Cancer Mortality Patterns around the San Onofre Nuclear Power Plant, 1960–1978

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Abstract: Because of the recent concern over possible health effects associated with nuclear power plants, cancer mortality patterns in Southern California have been examined for time periods before the San Onofre nuclear power plant began commercial operation in 1968 and since then. This is one of America's older plants and is surrounded by major population centers in Orange, Riverside, and San Diego Counties. Infant mortality rates and age-adjusted mortality rates for leukemia, lung cancer, all cancer, and all causes have been calculated and compared for Orange, Riverside, and San Diego Counties, for California, and for the United States during 1960–1978. In addition, childhood leukemia death rates and clusters have been examined in detail in the communities within 25 miles of San Onofre. The cancer and total mortality rates near San Onofre have remained essentially identical to the corresponding rates in California and United States from 1960 to 1978. There have been no significant radiation releases to the population surrounding the San Onofre plant and the cancer rates show no patterns which have been influenced by the presence of the plant. Although no radiogenic health effects would be expected, these results do provide a means of assessing overall mortality trends in the population. (*Am J Public Health* 1983; 73:83–92.)

Introduction

There has been recent concern over the possible human health effects of low level radiation due to radioactive releases from the Three Mile Island nuclear power plant in Pennsylvania,[1–3] the Haddam Neck and Millstone nuclear power plants in Connecticut,[4] the Maine Yankee nuclear power plant in Maine,[5] the Savannah River nuclear fuels plant in South Carolina,[6] and the Rocky Flats nuclear weapons plant in Colorado.[7] Over the past decade, the issue of health effects associated with nuclear facilities has resulted in some controversy among investigators, with a few claiming to show adverse effects[7,8] and most showing no effects.[5,6,9,10] This subject has been reviewed in detail elsewhere.[9,10]

In order to obtain further data, we have examined cancer mortality patterns around the San Onofre nuclear power plant, which is owned and operated by Southern California Edison Company and San Diego Gas and Electric Company. The plant, officially known as the San Onofre Nuclear Generating Station, began commercial operation in 1968 and generates 450 megawatts of power at full capacity. It is located in northern San Diego County within the Camp Pendleton Marine Corps Reservation at San Onofre, near the Pacific Ocean. It is about three miles south of the Orange County line and five miles south of San Clemente, and about 50 miles north of San Diego and 60 miles south of Los Angeles. Over 500,000 persons live within 25 miles of San Onofre and about 5,000,000 live within 50 miles, roughly the same number as live within similar distances of Three Mile Island.[2] Orange, Riverside, and San Diego Counties have residents that live within 25 miles of San Onofre.

It has recently been estimated that a serious accident at San Onofre, with portions of the nuclear fuel melting and a small portion of the available radionuclides released outside the containment building (category 4 accident), could result in about 350 excess cancer deaths if no protective actions were taken.[11] Using recent estimates for the linear dose-response model, a single absorbed dose of 10 rads (rems) of gamma or beta radiation among 500,000 persons would result in 835 excess cancer deaths over the lifetime of the individuals, which is a 1 per cent increase in the normal expectation of total cancer deaths.[12,13]

There have not been any known significant radioactive releases affecting the population around San Onofre. Nevertheless, determination of cancer mortality patterns for the period before and since operation began will document whether any change has occurred and will establish a baseline for comparison should an accident occur in the future. Ideally, a complete assessment of radiogenic health effects would measure leukemia incidence, other cancer incidence, thyroid abnormalities, genetic effects, and overall mortality as a function of individual exposure to radiation from San Onofre and other sources. Unfortunately, individ-

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ual radiation exposure measurements have not been made and mortality is the only health outcome that has been accurately and completely recorded for the defined populations surrounding San Onofre.

Methods

In order to calculate death rates in the counties surrounding the San Onofre nuclear reactor, death tapes containing a summary of each California resident death from 1960 through 1978 were obtained from the Vital Statistics Branch of the California Department of Health Services in Sacramento.[14] These were the only years for which computerized mortality data were available at the time the analysis was done. The underlying cause of death for each death was assigned by the California Vital Statistics Branch nosologist using the International Classification of Diseases, Seventh Revision for 1960–1968 and Eighth Revision for 1969–1978. These causes of death have been accepted as valid because of the careful procedures used by the California state nosologist.[14] This is the same disease classification system used by the National Center for Health Statistics (NCHS) for the Vital Statistics of the United States,[15,16] except that NCHS classified 1968 deaths according to the Eighth Revision instead of the Seventh Revision.

In addition, death certificate copies were purchased for all leukemia deaths under 20 years of age either occurring in or resident in Orange, Riverside, and San Diego counties during 1960–1978. The death tapes were then processed using the Statistical Analysis System (SAS) in order to obtain deaths by sex, race, five-year age group, year of death, cause of death, and county of residence.[17] The data contained on these tapes were then compared with summary tabulations in the annual Vital Statistics of California,[14] and there was essentially perfect agreement between the two sources. Comparison was made wherever possible between the tape data and the California data published in Vital Statistics of the United States[15] and agreement was generally within 1 per cent and almost always within 5 per cent. The small differences which occasionally exist between the official state and US tabulations of California deaths may be due to slight differences in the procedures for coding the underlying cause of death, in the definition of resident deaths, or in the cutoff date for late filed death certificates.

The population data were obtained from the full US Census of Population in 1960 and 1970,[18,19] preliminary reports of the 1980 US Census,[20] and 1980 age- and sex-specific population projections by the California Department of Finance.[21] Age-specific populations for 1980 may change slightly when complete data from the 1980 census are available. Although the San Onofre reactor began operation in 1968, the first full year of operation was 1969. For purposes of comparison before and since operation began, the following two time periods have been used: 1960–1968 and 1969–1978. The July 1, 1964 midpoint of the January 1, 1960 to December 31, 1968 period and the January 1, 1974 midpoint of the January 1, 1969 to December 31, 1978 period have been used to estimate the average population for each period. These averages are based on linear interpolation between the April 1, 1960, 1970, and 1980 US censuses, aided by 1980 age-specific population projections for the counties and state by the California Department of Finance. This procedure assumes that there was a constant growth rate from 1960 to 1970 and from 1970 to 1980. This assumption appears to be quite good based on the comparison of interpolated populations with 1964, 1974, and 1978 population estimates by the California Department of Finance[21] and 1974 population estimates by the Bureau of the Census.[22] The true population in non-decennial years is not precisely known.

Following the NCHS convention, age-specific death rates for 1960 and 1970 have been calculated using annual deaths and April 1 census populations instead of July 1 estimated populations.[15,16,23] The April 1 populations are generally slightly smaller than the July 1 populations because of population growth, but the difference is trivial. The 1978 age-specific death rates have been calculated using annual deaths and the April 1, 1978 population obtained by linear interpolation between the April 1, 1970 and April 1, 1980 census populations using the 1980 age-specific population projections. The 1960–1968 average annual age-specific death rates have been calculated by summing the 1960–1968 deaths and dividing by nine times the interpolated July 1, 1964 population and the 1968–1978 average annual age-specific death rates have been calculated by summing the 1969–1978 deaths and dividing by ten times the interpolated January 1, 1974 population. Age-adjusted death rates have been calculated from age-specific death rates for 19 age groups (<1, 1–4, 5–9, 10–14, . . ., 75–79, 80–84, and 85+ years) using the direct method with the 1940 US population as the standard.[23] The 1940 US population is the standard used in all major NCHS publications and has been used here to make comparisons with NCHS data possible.[15,16,23] Age-adjusted death rates for leukemia and total cancer during 1950–1969 have already been published by the National Cancer Institute using the 1960 US population as the standard for direct age adjustment[24] and they provide an independent determination of cancer rates.

In addition, both the infant death rate and the infant mortality rate have been calculated. The infant death rate is the annual number of infant deaths under one year of age divided by the midyear population of infants under one year of age. The infant mortality rate is the annual number of infant deaths under one year of age divided by the annual number of live births. In order to examine childhood leukemia clustering patterns, all leukemia deaths occurring to children under age 20 years have been grouped according to city of residence for cities and census county divisions within 25 miles of San Onofre.

Several demographic characteristics for Orange, Riverside, and San Diego Counties, the state of California, and the United States have been compared using 1970 census data.[19] Mean natural background radiation levels have been determined by the Environmental Protection Agency[25,26] and the National Council on Radiation Protection and Measurements,[27] and radioactive releases from San Onofre have been monitored and reported by Southern California Edison

TABLE 1—1960–1980 Total Population Counts and 1970 Demographic Characteristics for Orange, Riverside, and San Diego Counties, California, and US Whites

	Orange County	Riverside County	San Diego County	Orange Riverside San Diego Counties	California Whites	California Total	United States Whites
Total population counts*							
April 1, 1960	703,925	306,191	1,033,011	2,043,127	14,455,230	15,717,204	158,831,732
April 1, 1970	1,420,386	459,074	1,357,854	3,237,314	17,761,032	19,953,134	177,748,975
April 1, 1980	1,931,570	663,923	1,861,846	4,457,339		23,668,562	
April 1, 1970 Demographic Characteristics**							
Median age (years)	26.2	29.4	25.6	26.4	28.6	28.1	28.9
% Non-White	2.7	6.9	7.8	5.9	0.0	11.0	0.0
% Urban	98.9	78.5	93.6	93.2	90.3	90.9	72.4
% In SMSA	100.0	100.0	100.0	100.0	93.0	92.7	67.8
% Born in state of residence	40.9	37.9	34.3	37.1	47.6	47.4	68.1
% In same county in 1965 (ages 5+)	62.8	62.7	62.7	62.7	71.7	71.8	75.8
Median years of education (ages 25+)	12.6	12.3	12.4	12.5	12.4	12.3	12.1
Median family income in 1969	$12,245	$8,997	$10,133	$10,691	$10,969	$10,732	$9,961
Per capita income in 1969	$3,899	$3,097	$3,392	$3,523	$3,760	$3,632	$3,314
% Professional, technical and kindred workers (of employed aged 16+)	19.8	15.2	18.7	18.6	16.7	15.3	15.5
Mean elevation (feet)			42			391	707
Mean natural radiation (in mrem/yr)			87			79	84

*Data obtained from references 18–20.
**All data obtained from reference 19, except for mean elevation and mean natural radiation in reference 25.

Company.[28] Radioactivity in the environment and offsite radiation levels are also monitored by independent laboratories that are audited by the US Nuclear Regulatory Commission and the California Department of Radiologic Health.

Results

Table 1 summarizes the total populations in 1960, 1970, and 1980 for Orange, Riverside, and San Diego Counties, the state of California, and the United States. In addition, Table 1 compares the following demographic characteristics in Orange, Riverside, and San Diego Counties, the state of California, and the United States as of the April 1, 1970 US Census of Population:[19] median age; per cent non-White; per cent urban; per cent in Standard Metropolitan Statistical Area (SMSA); per cent born in state of residence; per cent in same county in 1965 for ages 5+; median years of education for ages 25+; median family income in 1969; per capita income in 1969; and per cent professional, technical, and kindred workers of employed persons aged 16+. Also included are mean altitude above sea level and mean natural radiation levels for various populations.[25]

The radiation releases from San Onofre can best be explained by comparison with Three Mile Island. The March 28, 1979 reactor accident at Three Mile Island released on the order of 10,000,000 curies of radioactive gas to the surrounding environment, mostly in the initial 30 hours, based on installed radiation monitoring equipment and special surveys.[3] Consequently, it is estimated that some two million nearby residents each received an average additional radiation dose of about 1.5 millirems, compared with a natural background radiation level of about 100 millirems annually. The approximately 3,000 person-rems (2,000,000 persons times 1.5 millirems) of additional radiation will add at most one additional cancer death to an expected lifetime total of about 400,000 cancer deaths among these residents. Obviously the Three Mile Island accident is much less severe than the hypothetical category 4 accident discussed in the Introduction. At San Onofre the largest releases of radioactive gases occurred in 1972 during operation with several defective fuel elements. The total gaseous discharge was less than 20,000 curies over a one-year period,[28] leading to no measurable increase in the off-site radiation exposure relative to the natural background radiation of about 87 millirems per year.[25] No radioactive gases were released from San Onofre before 1969.[28] Medical and dental irradiation approximately equal the natural background radiation for the average person[12] and the combined total is far greater than any radiation released from San Onofre.

The mortality patterns focus on infant mortality rates, leukemia, lung cancer, total cancer, and total mortality. Infant mortality and leukemia are relatively sensitive indicators of radiation exposure; lung cancer is a rough indicator of

TABLE 2—1950–69 Average Annual Age-adjusted Death Rates (deaths/100,000) in Orange, Riverside, and San Diego Counties, California, and United States for selected causes (age-adjusted by direct method to 1960 US population)‡

Cause of death and sex-race group	Age-adjusted Death Rate (deaths/100,000)					
	Orange County	Riverside County	San Diego County	Orange Riverside San Diego Counties*	California	United States
Leukemia (ICD6** No. 204)						
White males	8.7 (489)***	7.6 (232)	8.5 (669)	8.4 (1390)	8.73	8.81
White females	6.3 (425)	5.3 (177)	5.4 (483)	5.7 (1085)	5.84	5.74
Non-White males	4.1 (4)	7.7 (12)	6.4 (28)	5.8 (44)	6.13	5.77
Non-White females	2.2 (1)	5.3 (7)	2.8 (13)	3.0 (21)	4.20	3.88
Lung cancer (ICD6 Nos. 162–163)						
White males	40.6 (2021)	36.2 (1124)	41.2 (2998)	40.2 (6143)	40.09	37.98
White females	7.6 (481)	6.3 (212)	8.0 (709)	7.6 (1402)	7.52	6.29
Non-White males	19.8 (14)	30.1 (41)	32.2 (95)	27.6 (150)	35.97	36.67
Non-White females	3.7 (2)	6.3 (7)	8.3 (21)	6.4 (30)	7.53	6.27
All cancer (ICD6 Nos. 140–205)						
White males	159.0 (7928)	152.7 (4781)	164.3 (12036)	160.7 (24745)	171.39	174.04
White females	119.2 (7674)	112.4 (3809)	124.6 (11152)	120.9 (22635)	128.09	130.10
Non-White males	96.2 (77)	156.8 (213)	168.5 (484)	141.8 (774)	170.77	184.28
Non-White females	62.8 (42)	123.7 (149)	114.7 (341)	98.1 (532)	124.10	139.18

*Three-county weighted average using April 1, 1960 county population weights: Orange (34.5%), Riverside (15.0%), San Diego (50.5%).
**ICD6 means International Classification of Diseases, Sixth Revision.
***Parenthesis contain number of deaths upon which the death rate is based.
‡Taken from reference 24.

TABLE 3—1960–78 Average Annual Age-adjusted Death Rates (deaths/100,000) in Orange, Riverside and San Diego Counties, California, and United States for Selected Causes and Selected Years (age-adjusted by direct method to 1940 US population)

Cause and Year of Death	Age-adjusted Death Rate (deaths/100,000)					
	Orange-Riverside-San Diego Counties		California Whites		US Whites***	
	Males	Females	Males	Females	Males	Females
Leukemia (ICD7* No. 204 and ICD8* Nos. 204–207)						
1960	7.3 (74)**	4.5 (50)	7.3	5.1	7.9	5.2
1970	7.3 (120)	4.2 (81)	7.4	5.0	7.3	4.7
1978	7.0 (163)	3.7 (104)	6.7	3.9	6.9	4.2
1960–68	6.7 (782)	4.7 (624)	7.5	4.9		
1969–78	6.7 (1320)	4.0 (950)	6.9	4.3		
Lung cancer (ICD7 Nos. 162–163 and ICD8 No. 162)						
1960	30.9 (279)	4.8 (52)	33.0	5.5	31.8	4.6
1970	44.0 (680)	11.3 (200)	45.5	12.1	46.8	9.5
1978	49.3 (1130)	21.7 (568)	49.7	20.6	54.3	16.0
1960–68	37.2 (3912)	7.3 (902)	38.6	7.6		
1969–78	47.3 (8951)	15.5 (3374)	47.8	15.5		
All cancer (ICD7 Nos. 140–205 and ICD8 Nos. 140–209)						
1960	126.4 (1195)	102.2 (1096)	139.4	106.9	141.6	109.5
1970	145.4 (2326)	104.2 (2022)	151.4	111.6	154.3	107.6
1978	151.3 (3565)	114.4 (3240)	153.7	115.5	161.2	109.0
1960–68	132.8 (14611)	99.3 (12884)	144.1	106.5	146.0	107.9
1969–78	144.8 (28311)	105.3 (24823)	150.9	111.3	156.9	107.6
All causes						
1960	861.3 (8614)	504.9 (6235)	894.0	525.0	917.7	555.0
1970	768.5 (12801)	453.0 (10277)	847.6	487.6	893.4	501.7
1978	669.0 (16188)	394.0 (13410)	712.2	417.4	773.1	425.5
1960–68	794.0 (91816)	465.1 (69899)	879.8	504.9	911.0	532.9
1969–78	710.1 (143131)	419.8 (117407)	777.7	451.4	844.7	468.3

*ICD7 means International Classification of Diseases, Seventh Revision (used for 1960–68) and ICD8 means International Classification of Diseases, Eighth Revision (used for 1969–78).
**Parentheses contain number of deaths upon which death rate is based. Deaths of unknown age (about 0.03% of total) have been excluded from calculation.
***Taken from references 15 and 16.

TABLE 4—1960–78 Annual or Average-annual Infant Death Rate and Infant Mortality Rate for Orange, Riverside and San Diego Counties, California Whites, and US Whites

Type of Rate and Year of Death	Orange-Riverside-San Diego Counties		California Whites		US Whites*	
	Males	Females	Males	Females	Males	Females
Infant death rate (deaths per 1000 population under 1 year)						
1960	28.3 (738)	19.8 (484)	27.2	19.7	26.9	20.1
1970	19.7 (571)	15.6 (426)	19.7	15.2	21.1	16.1
1978	11.5 (403)	9.6 (320)	11.0	8.6	13.6	10.7
1960–68	25.8 (6340)	19.2 (4435)	24.7	18.4	24.4	18.3
1969–78	14.6 (4638)	11.4 (3416)	14.2	10.9	17.4	13.2
Infant mortality rate (deaths under 1 year per 1000 live births)						
1960	27.4 (738)	18.7 (484)	26.0	18.8	26.0	19.6
1961	26.9 (758)	21.6 (575)	25.6	19.3	25.4	19.3
1962	27.2 (778)	20.2 (545)	24.7	18.9	25.4	19.1
1963	26.2 (756)	19.6 (539)	24.6	18.4	25.1	19.0
1964	27.3 (785)	18.2 (501)	23.8	17.8	24.4	18.6
1965	25.8 (702)	19.7 (508)	24.1	18.2	24.4	18.5
1966	24.4 (637)	18.4 (459)	22.6	17.2	23.5	17.7
1967	22.9 (605)	15.4 (389)	21.6	15.9	22.4	16.9
1968	20.8 (570)	16.6 (432)	21.2	15.5	21.9	16.4
1969	20.6 (601)	14.9 (413)	20.2	14.8	20.9	15.8
1970	18.7 (571)	14.7 (426)	18.6	14.4	20.0	15.4
1971	18.7 (522)	14.4 (383)	17.9	13.7	19.3	14.7
1972	17.3 (464)	12.7 (327)	16.9	13.2	18.6	14.0
1973	15.5 (418)	13.2 (334)	15.9	11.9	17.9	13.6
1974	15.3 (438)	12.0 (323)	15.3	11.2	16.8	12.8
1975	14.4 (414)	11.5 (316)	14.5	11.2	15.9	12.3
1976	13.5 (406)	9.5 (273)	13.3	10.7	14.8	11.7
1977	12.5 (402)	9.9 (301)	12.9	10.1	13.9	10.7
1978	12.3 (403)	10.1 (320)	12.3	9.7	13.4	10.6

*Taken from reference 15.

smoking status; total cancer and total mortality indicate the overall healthiness of the population.

Table 2 indicates the 1950–1969 cancer patterns in Orange, Riverside, and San Diego Counties, compared with California and the United States for Whites and non-Whites, using data previously published by the National Cancer Institute.[24] The leukemia and lung cancer rates are the same to within 5 per cent in all the geographical areas. The total cancer rates are about 8 per cent less in the three counties during the 1950–1969 period, which was essentially all before operation of San Onofre. These 1950–1969 rates are shown for reference purposes only and cannot be directly compared with the 1960–1978 rates because of the different age standardizations. They represent an independent determination of the general cancer patterns in Orange, Riverside, and San Diego Counties relative to California and the United States prior to 1970.

Table 3 indicates the leukemia, lung cancer, total cancer, and total mortality rates during 1960, 1970, 1978, 1960–1968, and 1969–1978. The 1960–1968 and 1969–1978 periods indicate average annual cancer rates before and during operation of the San Onofre plant, respectively. The comparison of Orange, Riverside, and San Diego Counties with California Whites and US Whites indicates the same patterns as in Table 2. In summary, the leukemia rates are the same in all areas and have declined by 5 to 10 per cent since 1970; the lung cancer rates are similar in all areas and have increased by about 50 per cent in men and about 300 per cent in women from 1960 to 1978; total cancer is about 10 per cent lower in the counties in 1960 but close to the state and national rates in 1978; when comparing 1960–1968 with 1969–1978, the county cancer rates show the same small increases as the state and national rates; total mortality rates are 10 to 15 per cent lower in the counties relative to the nation and all areas show about a 20 per cent decline from 1960 to 1978. The 1978 and 1969–78 death rates could change slightly when they are recalculated using final age- and sex-specific populations from the 1980 US Census. As mentioned early, all death rates in Table 3 are age-adjusted to the 1940 US population and are smaller in absolute value than if they were age-adjusted to the 1950, 1960, or 1970 US population. But the relative comparison of rates is the same no matter what age standardization is used.[29]

Table 4 indicates the infant death rate for 1960, 1970, 1978, 1960–1968 and 1969–1978 for Orange, Riverside, and San Diego Counties, California Whites, and US Whites. It also indicates the infant mortality rate for individual years from 1960 through 1978 for these same populations. The data indicate continuous declines in all areas, with an overall decline of about 50 per cent from 1960 to 1978. Continuous declines also occurred in the neonatal (less than 28 days) death rate and the postneonatal (from 28 days up to 1 year)

TABLE 5—1960–78 Childhood Leukemia Death Rates and Leukemia Cluster Death Rates for Ages 0–19 Years within Orange, Riverside and San Diego Counties, California, and United States

	Leukemia Death Rates ages 0–19 years (deaths/100,000)					
	1960–68 death rate			1969–78 death rate		
	July 1, 1964 Population for Ages 0–19	Total Deaths	Annual Death Rate	January 1, 1974 Population for Ages 0–19	Total Deaths	Annual Death Rate
Within 10 miles of San Onofre (Census Tracts D-21 and D-22)*	5182	4	8.6 [2.3→22.0]**	8699	1	1.1 [0.03→6.1]
Within 25 miles of San Onofre***	~98,337	33	~3.7 [2.5→5.2]	~164,350	30	~1.8 [1.2→2.6]
Orange, Riverside,San Diego Counties	1,002,418	320	3.55 [3.2→4.0]	1,301,130	290	2.23 [2.0→2.5]
California Whites	5,792,924	1948	3.74	6,449,777	1634	2.53
US Whites	62,106,717	19590	3.50	63,445,000	15653	2.47

	Cluster Death Rate			1960–78 Death Rate		
Childhood Leukemia Clusters with Time Period	Estimated Population for Ages 0–19	Cluster Deaths	Annual Death Rate	April 1, 1970 Population for Ages 0–19	Total Deaths	Annual Death Rate
Oceanside May 24, 1966–June 11, 1967	~14,000	3	~20 [4→60]	16,010	12	3.9 [2.0→6.9]
Carlsbad April 27, 1967–January 19, 1968	~5,200	5	~130 [43→310]	5,775	8	7.3 [3.1→14.4]
Mission Viejo October 1, 1971–December 12, 1971	~6,000	3	~250 [52→734]	5,438	5	4.8 [1.6→11.2]
Within 25 miles of San Onofre				~133,700	63	~2.5
Orange, Riverside, San Diego Counties				1,247,002	610	2.57
California Whites				6,410,378	3582	2.94
US Whites				65,372,043	35243	2.84

*Census tract boundaries since 1960 are Orange County line, east to Gas and Electric Power Line, north to San Juan Creek, west to Pacific Ocean, south to county line.

**Numbers in brackets give 95% confidence interval for death rate assuming Poisson variation.

***See Table 6 for detailed description.

death rate. There is no indication that the county infant mortality rates have been influenced in any unusual way since 1968.

Table 5 indicates the leukemia death rate for children less than 20 years of age for progressively closer geographical areas around San Onofre: Orange, Riverside, and San Diego Counties; all county census divisions and cities within a 25-mile radius of San Onofre; and the population residing within 10 miles of San Onofre, consisting of 1960 Census Tracts D-21 and D-22,[18] which retained the same boundaries up to 1980.[19,20] The county census divisions and cities within the 25 mile radius are listed in Table 6, along with their 1960, 1970, and 1980 populations and the number of childhood leukemia deaths in 1960–1968 and 1969–1978. Most of the places with no population count are small and unincorporated and it is not possible to get the precise number of inhabitants within these areas, but the county divisions include these places. The Pendleton division, consisting of Camp Pendleton Marine Corps Reservation, has been excluded because it has a highly transient population of young recruits undergoing advanced training and no leukemia deaths were reported among persons under age 20 with Camp Pendleton as a place of residence. Almost the entire population of the camp is located about 15 miles from San Onofre. No subdivision of individual census divisions or cities has been attempted near the 25-mile radius and so the true population within 25 miles may be off by up to 10 per cent.

Nevertheless, it is possible to calculate the approximate childhood leukemia death rate before and since the reactor began operation. In all areas the death rate has declined substantially, although the 95 per cent confidence interval on

TABLE 6—Population and Childhood Leukemia Deaths for County Census Divisions, Cities, and Major Places within 25 miles of San Onofre since 1960 (population for some places not available)

Census Divisions and Cities	Total Population—All Ages			Leukemia Deaths Aged 0–19		
	April 1, 1960	April 1, 1970	April 1, 1980	1960–68	1969–78	1960–78
Orange County—southern divisions						
Central Coast division	80,353	153,007	171,563			
Balboa				0	0	0
Corona del Mar				1	0	1
Costa Mesa	37,550	72,660	82,291	6	6	12
Laguna Beach	9,288	14,550	17,860	1	1	2
Newport Beach	26,564	49,422	63,475	4	2	6
El Toro division	8,188	19,600	76,627			
El Toro		8,654		0	2	2
Irvine			62,134	0	2	2
South Coast division	15,443	49,191	134,655			
Capistrano Beach	2,026	4,149		0	0	0
Dana Point	1,186	4,745		0	0	0
Laguna Hills		13,676		0	0	0
Laguna Niguel		4,644		0	0	0
San Clemente	8,527	17,063	27,325	4	1	5
San Juan Capistrano		3,781	18,959	1	1	2
South Laguna	2,000	2,566		0	0	0
Trabuco division	1,897	13,818	67,939			
Mission Viejo		11,933		0	5	5
Total—southern divisions	105,881	235,616	450,784			
Riverside County—western divisions						
Elsinore Valley division	5,971	9,232	20,154			
Alberhill				0	0	0
Lake Elsinore	2,432	3,530	5,982	0	1	1
Wildomar				0	0	0
Murrieta division	1,998	2,769	11,530			
Murrieta				0	0	0
Temecula				0	1	1
Total—western divisions	7,969	12,001	31,684			
San Diego County—northern divisions						
Carlsbad division	10,087	16,005	~38,010*			
Carlsbad	9,253	14,944	35,490	6	2	8
Fallbrook division	~7,835**	12,038	23,504			
Bonsall				0	0	0
De Luz				0	0	0
Fallbrook	4,814	6,945		0	1	1
Rainbow				1	0	1
Oceanside division	26,144	41,465	~78,537*			
Oceanside	24,971	40,494	76,698	8	4	12
San Luis Rey				0	0	0
Pendleton division***		32,861	26,705			
Camp Pendleton				0	0	0
San Onofre				0	0	0
Vista division	20,689	29,981	~43,517*			
Buena		24,688	35,834	0	0	0
Vista				1	1	2
Total—northern divisions excluding Pendleton division	~64,755	99,489	~183,568			
Total—Orange, Riverside, and San Diego County divisions excluding Pendleton division	~178,605	347,106	~666,036	33	30	63

*1980 population based on assumption that division increased at same rate since 1970 as its major city.
**1960 population based on assumption that Fallbrook division changed population from 1960 to 1970 at the same rate as the Carlsbad, Oceanside, and Vista divisions combined.
***Pendleton division excluded from totals because of transient population with no resident leukemia deaths.

each death rate is wide because of the small number of deaths. All changes are consistent with the national decline from 3.5 to 2.5 deaths per 100,000 population from 1960–1968 to 1969–1978. This decline is generally attributed to the greatly improved survival rates for childhood leukemia during the 1970s.[30] Childhood leukemia has virtually disappeared as a cause of death within 10 miles of San Onofre—only one such death during 1969–1978 as compared to four during 1960–68.[14]

The final issue to be investigated is that of childhood

leukemia clusters around San Onofre, since clusters could be an indication of unusually high exposure to radiation.[12,31] Leukemia clusters have been reported many times during the last 60 years, usually in connection with viruses[32] or environmental exposures.[33] However, in order to have a radiation-induced cluster that is etiologically significant, an unusually large number of cases or deaths must occur within a short time period and small geographical area and there must be evidence of high radiation exposure. Otherwise, the cluster is most likely a statistical artifact.[32] For all county census divisions and cities within 25 miles of San Onofre, we have summarized in Table 6 the number of childhood leukemia deaths less than 20 years of age among their residents, along with their total 1960, 1970, and 1980 Census populations.[18–20] Appendix Table 1 contains detailed demographic and cause of death information on each of the 63 childhood leukemia deaths summarized in Table 6. No formal analysis of all possible clusters has been done, because the purpose here is simply to demonstrate how easy it is to construct clusters.

The greatest concentration of childhood leukemia deaths occurred in Oceanside, Carlsbad, and Mission Viejo. Indeed, there are at least three clusters of note shown in Table 5. We have not considered clusters based on less than three deaths or based on census tracts within cities. There were three deaths reported between May 24, 1966 and June 11, 1967 in Oceanside with an average population of about 14,000 under age 20, resulting in an annual rate of 20 deaths per 100,000 population. There were five deaths reported between April 24, 1967 and January 19, 1968 in Carlsbad with a population of about 5,200 under age 20, resulting in an annual death rate of 130 per 100,000. These clusters could not have been caused by radiation from San Onofre, which was not operational until 1968. The final cluster was in Mission Viejo, where three deaths were reported between October 1, 1971 and December 12, 1971 among a population of about 6,000 under age 20, resulting in an annual rate of 250 deaths per 100,000 population. Mission Viejo is located 15 miles from San Onofre and it is not likely that these three children were exposed to radiation from San Onofre. None of the three died of myeloid leukemia, the form of leukemia most strongly associated with radiation.[12] No attempt has been made to find information on these children other than what is on their death certificates.

An indication that these three clusters are random fluctuations is the fact that the childhood leukemia death rate for the entire 1960–1978 period is only about 4 per 100,000 in Oceanside, about 7 per 100,000 in Carlsbad and about 5 per 100,000 in Mission Viejo, as shown in Table 5. The rates in these cities for times other than the cluster periods are only 3 per 100,000, which equal the Orange, Riverside, and San Diego County average. The death rates in these clusters are similar to or greater than the rates for previously reported clusters,[31–33] and indicate that it is possible to find up to a 100-fold variation in childhood leukemia rates. The difficulty in relating leukemia to low-level radiation has recently been illustrated by a study of all leukemia cases occurring in Olmsted County, Minnesota residents from 1955 to 1974, which showed no increase in the risk of developing leukemia following medical irradiation of up to 300 rad to the bone marrow.[34]

In summary, the infant mortality, childhood leukemia, and total death rates have declined markedly, the total leukemia death rate has declined slightly and the total cancer rate has increased slightly due primarily to the greatly increased lung cancer death rate. The largest childhood leukemia clusters that can be constructed in cities within 25 miles of San Onofre appear to be random fluctuations that are not connected to radiation exposure.

Discussion

Because of the concern about low levels of radiation exposure generated by the Three Mile Island accident, we have examined cancer and total mortality trends around the San Onofre nuclear power plant even though the maximum annual release of radioactive gases from San Onofre has been only about 10^{-3} times the March–April 1979 release from Three Mile Island and is trivial compared to natural background radiation levels. Since no significant radiation releases have occurred at San Onofre, one would not expect cancer rates in the surrounding populations to be influenced by their near proximity, and this, indeed, is what has been found. Even a serious (category 4) accident at San Onofre would result in less than a 1 per cent increase in the normal expectation of total lifetime cancer deaths. It is unlikely that such a small change in cancer rates could be detected because of methodologic limitations and because of the various other factors which also influence cancer rates, such as cigarette smoking and socioeconomic status.[9,10] Also, it would be difficult to relate radiation exposure to cross-sectional population and mortality statistics because of mobility of the population. The communities nearest the reactor have grown rapidly during the 1970s so many of the current residents have not lived near San Onofre for more than a few years. Cancer deaths among these recent immigrants would logically be related to their entire life experience.

In order to properly assess the effects of any excess radiation from San Onofre, it would be necessary to measure the actual radiation from all sources received by individual residents and then follow these individuals for many years for subsequent development of cancer, as has been done with very highly exposed populations in Hiroshima and Nagasaki.[12] Given the limitations of the present study design, all that can be concluded is that there are no unusual or unexpected patterns in the death rates due to cancer and other causes in the populations near San Onofre. Steadily declining rates of infant mortality and leukemia suggest that factors such as improved medical care and a higher standard of living are of much greater importance than any low level radiation exposure.

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APPENDIX TABLE 1—Individual 1960–78 Leukemia Deaths Aged 0–19 Years Residing within about 25 Miles of San Onofre Nuclear Power Plant

Sex	Date of Death			Age at Death (years)	Years in California*	Years in County of Residence*	State of Birth	Residence Address		Cause of Death**	
	Month	Day	Year					City	County	Stated by Physician	ICD by Nosologist
M	3	1	1960	4	4	4	CA	Oceanside	San Diego	ALL	204.3
F	3	2	1960	5	4		MI	Costa Mesa	Orange	AL	204.3
M	3	13	1960	11	11	11	CA	Rainbow	San Diego	ALL	204.3
M	7	9	1960	13	5	1	MN	Oceanside	San Diego	ALL	204.3
M	7	30	1960	3	3		CA	Costa Mesa	Orange	L	204.4
M	9	5	1960	19	6		RI	Costa Mesa	Orange	AML	204.3
F	3	16	1961	7	7	7	CA	Vista	San Diego	ALL	204.3
M	12	20	1961	7	7	1	CA	Costa Mesa	Orange	AL	204.3
F	3	25	1962	6	6	6	CA	Costa Mesa	Orange	ALL	204.3
M	8	14	1962	16	15	4	NY	Newport Beach	Orange	AL	204.3
F	8	31	1962	13	13		CA	San Clemente	Orange	ALL	204.3
M	1	20	1963	5	4.5	4.5	HI	Corona del Mar	Orange	AL	204.3
F	8	4	1963	9	9	9	CA	Oceanside	San Diego	ALL	204.3
M	8	27	1963	15	10	10	CA	Carlsbad	San Diego	ALL	204.3
F	12	23	1963	9	7	7	CA	Oceanside	San Diego	L	204.4
M	11	16	1964	4	4		CA	Costa Mesa	Orange	ALL	204.3
M	11	7	1965	6	1		NC	San Clemente	Orange	AL	204.3
F	2	17	1966	2	2		CA	Laguna Beach	Orange	ALL	204.3
F	3	14	1966	8	8		CA	San Juan Capistrano	Orange	AL	204.3
M	5	24	1966	19	8	8	HI	Oceanside	San Diego	AL	204.3
F	11	15	1966	1	1	1	CA	Newport Beach	Orange	AML	204.3
M	4	24	1967	16	1		NJ	Carlsbad	San Diego	AL	204.3
F	5	17	1967	18	5	5	SD	Oceanside	San Diego	ALL	204.3
M	5	18	1967	0	0	0	CA	Carlsbad	San Diego	L	204.4
M	6	11	1967	8	4	0.5	CO	Oceanside	San Diego	ALL	204.3
M	6	25	1967	13	12	8	NY	Carlsbad	San Diego	L	204.4
M	11	13	1967	13	13	13	CA	Carlsbad	San Diego	AL	204.3
F	11	29	1967	19	19	15	NJ	Newport Beach	Orange	AL	204.3
M	1	6	1968	11	11	11	CA	San Clemente	Orange	AL	204.3
M	1	19	1968	3	3	3	CA	Carlsbad	San Diego	ALL	204.3
M	7	27	1968	5	5	0.5	CA	Oceanside	San Diego	ALL	204.3
M	8	25	1968	19	19	12	CA	Newport Beach	Orange	AML	204.3
M	11	27	1968	7	7		CA	San Clemente	Orange	L	204.4
F	2	6	1969	5	5	5	CA	Mission Viejo	Orange	AML	205.0
F	5	22	1969	15	15		WA	Irvine	Orange	AML	205.0
M	9	24	1970	19	19		CA	Newport Beach	Orange	ALL	204.0
M	1	10	1971	5	2.5	2.5	Mexico	El Toro	Orange	ALL	204.0
F	7	4	1971	6	6	1.5	CA	Costa Mesa	Orange	ALL	204.0
M	10	1	1971	9	8		KS	Mission Viejo	Orange	ALL	204.0
M	11	28	1971	6	6	2	CA	Mission Viejo	Orange	ALL	204.0
M	12	12	1971	3	0.5	0.5	WI	Mission Viejo	Orange	L	207.9
F	6	4	1972	10	10	10	CA	Oceanside	San Diego	CML	205.1
F	10	27	1972	19	6	6	CA	Costa Mesa	Orange	ALL	204.0
F	12	25	1972	15	15	15	CA	Irvine	Orange	AML	205.0
F	5	15	1973	0.5	0.5	0.5	CA	Oceanside	San Diego	AML	205.0
M	9	5	1973	12	2		NJ	Mission Viejo	Orange	ALL	204.0
F	2	18	1974	6	6	6	CA	Laguna Beach	Orange	ALL	204.0
M	7	3	1974	6	2.5	2.5	MD	San Juan Capistrano	Orange	AML	204.0
M	11	9	1975	4	1.5	1.5	NC	Oceanside	San Diego	ALL	204.0
F	11	18	1975	15	15	15	CA	Costa Mesa	Orange	ALL	204.0
F	12	12	1975	5	5	5	CA	El Toro	Orange	ALL	204.0
F	5	4	1976	10	4.5	4.5	Italy	San Clemente	Orange	AML	205.0
M	8	17	1976	11	4	4	MA	Costa Mesa	Orange	AML	205.0
M	9	3	1976	13	13	13	CA	Costa Mesa	Orange	ALL	204.0
M	6	25	1977	2	2	2	CA	Temecula	Riverside	AML	205.0
M	7	6	1977	5	5	5	CA	Vista	San Diego	ALL	204.0
M	7	31	1977	8	7	4	NJ	Oceanside	San Diego	ALL	204.0
F	8	30	1977	5	3		KS	Lake Elsinore	Riverside	ALL	204.0
M	3	4	1978	13			CA	Fallbrook	San Diego	ALL	204.0
M	6	7	1978	7			CA	Carlsbad	San Diego	ALL	204.0
M	6	28	1978	7			NV	Newport Beach	Orange	ALL	204.0
M	7	17	1978	4			CA	Costa Mesa	Orange	ALL	204.0
M	9	17	1978	3			CA	Carlsbad	San Diego	ALL	204.0

*A blank entry means that number is not reported on death certificate.

**Cause of death as stated by physician and as coded by nosologist on death certificate:

	ICD7 (1960–68)	ICD8 (1969–78)
ALL = acute lymphatic leukemia	204.3	204.0
AML = acute myeloid leukemia	204.3	205.0
AL = acute leukemia	204.3	207.0
CML = chronic myeloid leukemia	204.1	205.1
L = leukemia, unspecified	204.4	207.9